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EXPERIMENTAL INVESTIGATION OF PHOTOVOLTAIC PERFORMANCE OF SILICON SOLAR CELL BY USING COPPER DOPED TIO_2 THIN FILM

CH. CHAITANYA[1], SANDEEP YECHURI[2] & K. RAMAKRISHNA[3]

[1]*Student, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India*

[2]*Assistant Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India*

[3]*Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India*

ABSTRACT

In the present work Copper (Cu) is used as a dopant element in titanium dioxide (TiO_2) crystal structure to enhance the photovoltaic performance of the silicon (Si) solar cells fabricated with TiO_2 thin film. Highly ordered Copper doped TiO_2 particles were synthesized by using hydrothermal method with different molar concentrations of 0.25, 0.5, 0.75, and 1.0% and by dispersing in 5 ml of ethanol. During this process Copper doped TiO_2 layers were coated on mesoporous TiO_2 films by spin coating process. The effect of Cu doping concentration on the photovoltaic performance of Si solar cell has been investigated. It is observed that power conversion efficiency of the Cu doped solar cells increased from 6.61% at 0.25% molar concentration to 8.86% at 0.5% molar concentration. Further it is observed that improvement in power conversion efficiency of the solar cells is superior with Cu doped TiO_2 when compared with the solar cells doped with other elements viz., Zn, Fe, Eu, Al.

KEYWORDS: Si solar Cell, TiO_2 Thin Film, Cu Doping & Efficiency

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Original Article

NOMENCLATURE

- **I** Current
- **V** Voltage
- $\mathbf{V_{oc}}$ Open Circuit Voltage
- $\mathbf{I_{sc}}$ Short Circuit current
- **η** Efficiency
- **PV** Photovoltaic
- **UV** Ultra Violet

INTRODUCTION

Solar cells or photovoltaic (PV) systems which provide clean electricity from sunlight have attracted a lot of attention due to their ability, reliability, and accessibility. The performance of solar cell can be improved or enhanced by coating with subwavelength semi-conductor nano-structures which brings in reduced reflection losses and better light manipulation and/or trapping at sub-wavelength scale [1]. PV cells are composed of layers of semiconductor materials, conventionally silicon in its different crystalline forms, i. e. mono- or multi-crystalline. While the crystallized silicon does not show promising electric conducting behavior, selectively contaminating the semiconductor at a controlled level, namely doping, helps to generate a good amount of electric current [2, 3]. Thus for achieving best efficiency, it is necessary to design solar cells with specific geometries to benefit from some interesting characteristics, e.g., using metallic and semiconductor nano-structures which can cause extraordinary optical transmission for light localization [4-6]. Though semiconductor nanostructures improve light absorption performance [7-10] the solar cells need to be designed properly taking into account larger surface to volume ratio provided for sunlight exposure on the PV cell surface once covered with nano-structures [11]. Silicon solar cells, coated with dielectric interfaces like Cu doped TiO_2 can increase their efficiency compared with cells coated with other elements.

Al-doped TiO_2 layers are generally coated on the mesoporous TiO_2 films by a chemical bath deposition process, followed by sintering at 500°C. These cells exhibit an improvement in two aspects enhancing the electron transport and suppressing the charge recombination process. The power conversion efficiency of Al-doped TiO_2 cell is superior than mesoporous TiO_2 coated cell [12]. Similarly, many authors have reported an improvement in solar cell efficiency by overcoating on solar cells with Co, Cd, Fe, Zn, Gd, Eu doped TiO_2 thin films with different doping concentrations [13-18]. Co-doped with TiO_2 generates maximum efficiency of 5.66% [13]. Cd-doped with TiO_2 generates maximum efficiency of 3.06% [14]. Fe doped with TiO_2 generates maximum efficiency of 2.78% [15]. Zn doped with TiO_2 generates maximum efficiency of 6.58% [16]. Gd-doped TiO_2 generates maximum efficiency of 1.18% [17] and Eu doped with TiO_2 different concentrations gives maximum efficiency of 2.47% [18].

To the best of author's knowledge, till now no reports were found with Cu doped TiO_2. Most of the time authors have concentrated on surface modification with copper for applications such as photocatalytic etc. [19-23]. Thus the present paper is aimed at analyzing the characteristics of a single crystalline Si solar cell coated with copper doped TiO_2. The variation in efficiency & I-V characteristics is compared with the performance of cells doped with other material and found that Cu doped TiO_2 is superior to cells with other doping materials.

EXPERIMENTAL

With the impregnation method, copper doped mesoporous TiO_2 particles were obtained by mixing the as-synthesized particles into a beaker containing an aqueous solution of $CuCl_2 \cdot 2H_2O$ with a copper concentration of 0.25, 0.5, 0.75 and 1%. The mixture is stirred well for 1-hour maintaining at $\sim 70^0$C after cooling, the sample is washed with de-ionized water and filtered. It is dried in a hot air oven for 6 hours at 100 ^{0}C to get Cu doped mesoporous TiO_2, which is pale brown in colour.

Different concentration solutions for coating were prepared by dispersing the known amount of Copper modified TiO_2 in 5 ml of ethanol. These solutions were coated on single crystalline Si solar cells with the assistance of a spin coating unit of VB Ceramics at a high speed of typically around 500 rpm for 40 sec followed by annealing at 450^{0}C for 1-hour in

order to evaporate ethanol. Open circuit voltage (V_{oc}), short circuit current (I_{sc}) for coated cells were analysed using solar module analyser of MECO (model no. 9009). An experimental setup was designed and framed to measure the above parameters. An incandescent light was placed in such way that the distance from light to the test bed is fixed. The intensity of the incident light is evaluated with the help of lux meter (MASTECH; Model No: MS6610).

UV-Vis Analysis of TiO_2 and Cu Doped TiO_2

Mesoporous TiO_2 and Cu doped TiO_2 at different concentrations were characterized using UV-Vis spectrophotometer (Lab India) as shown in fig 1(a) and 1(b). Band gap energy values are calculated by representing the reflectance.

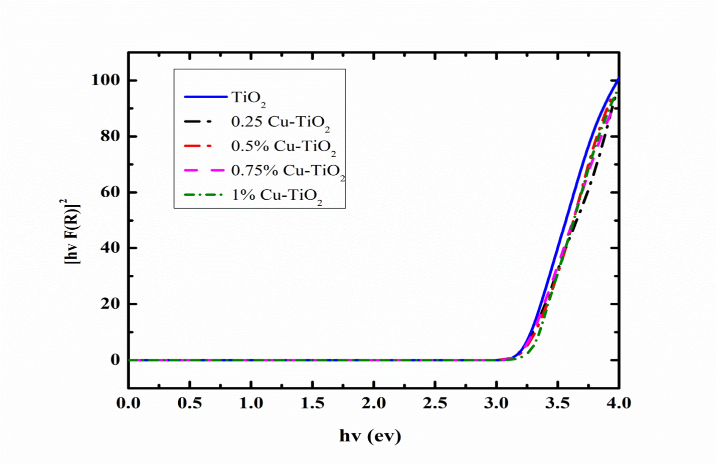

Figure 1(a): Band Gap Curves of Mesoporous TiO_2 and Cu Doped TiO_2 at 100 ^{0}C at Different Concentrations

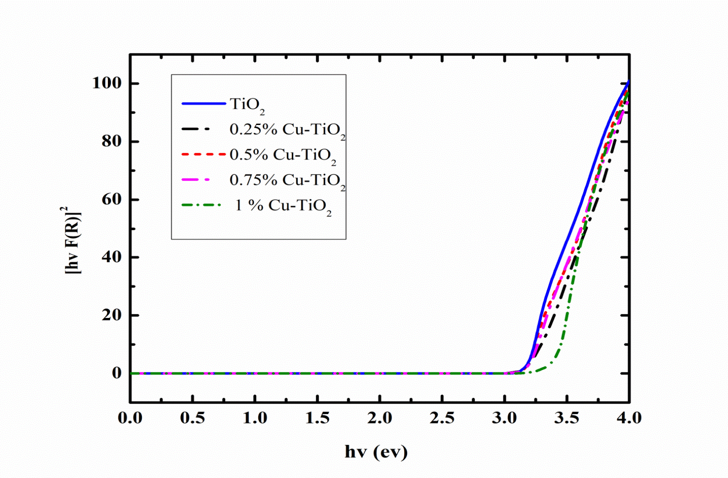

Figure 1(b): Band Gap Curves of Mesoporous TiO_2 and Cu Doped TiO_2 at 120 ^{0}C Different Concentrations

Figure 1(a) and figure 1(b) reveals that the band gap curves of mesoporous TiO_2 and Cu doped TiO_2 at two different temperatures, i. e. 100^{0}C and 120^{0}C. The values are obtained by inducing the tangent to the intersection of hv (horizontal axis). It is observed that there is a slight increment in the band gap values at every particular increase in the molar concentration of Cu doped TiO_2 cells table(1). When compared with a mesoporous TiO_2 solar cell the band gap values of Cu doped TiO_2 solar cells are superior.

Table 1: Band Gap Values of TiO_2 and Cu-Modified TiO_2 Synthesized at Different Process Temperatures

Molar Concentration of Cu-TiO_2 (%)	Cu-TiO_2 at Different Process Temperatures	
	100 ^{0}C	120 ^{0}C
0	3.19	3.26
0.25	3.21	3.29
0.5	3.22	3.32
0.75	3.27	3.38
1.0	3.33	3.43

Due to shifting of electrons from lower energy d-orbital to higher energy d-orbital in copper, strong absorption is observed at 700-800nm [25]. The absorption edge slightly shifts to the visible region for Cu doped TiO_2 when compared to pure mesoporous TiO_2. Hence it can be inferred that modifying TiO_2 with copper increases the light absorption capacity of mesoporous TiO_2 with visible-light response.

RESULTS AND DISCUSSIONS

In order to enhance the transport properties of the TiO_2 layer doping with metal ions, the method is explained in experimental. Cu was used as a dopant material in this study and the power conversion efficiency at different molar concentrations is studied and compared with other doping elements. As a result of doping of Cu in TiO_2 layers, there is an increase in the photo-catalytic activity [24]. This increase in photo-catalytic activity leads to increase in power conversion efficiency of the Cu doped TiO_2 Si solar cell.

To investigate the influence of surface modification on the photo- voltaic properties of Si solar cell the short circuit current (I_{sc}), open circuit voltage (V_{oc}) characteristics are shown in figure (2) and table (2). Compared with the other molar concentration cells 0.5% Cu doped TiO_2 cell yields high open circuit voltage (V_{oc}) of 0.52 V and short-circuit current (I_{sc}) of 134 mA from the table (2).

Table 2: Open Circuit Voltage (V_{oc}), Short Circuit Current (I_{sc}) and Efficiency (η) of Different Molar Concentrations of Cu Doped TiO_2 Coated on TiO_2 Layered Solar Cells

Molar Concentration of Cu- TiO_2 (%)	Voltage (V_{OC}) (V)	Current (I_{SC}) (mA)	Efficiency (η) (%)
0.25	0.51	78	6.21
0.5	0.52	134	8.86
0.75	0.52	93	6.68
1.0	0.41	72	3.73

Table 2 depicts that for 0.5% molar concentration of Cu doped TiO_2 the efficiency value is 8.86 %. The increase in power conversion efficiency at this concentration can be attributed to decrease in electron-hole recombination and enhance charge separation which in turn increases the efficiency of the solar cell. It is evident that as in the table (2) the concentration increases power conversion efficiency up to certain level and starts decreasing.

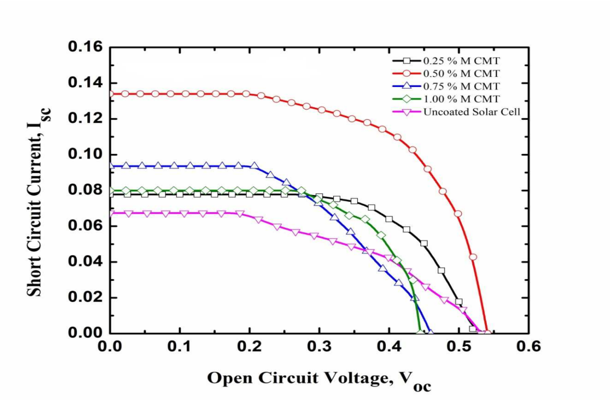

Figure 2: I-V Curves of Different Concentrations of Cu Doped TiO_2

Figure 2 reveals I-V curves of Cu doped TiO_2 with different molar concentrations (0.25 to 1.0 %). It is observed from the figure that the short circuit current (I_{sc}) is 134 mA and open circuit voltage (V_{oc}) of 0.52 V is produced for 0.5% Cu doped TiO_2 cell from the table (2). When the concentration of doping increases there is the decrease in the production of short circuit current (I_{sc}) and open circuit voltage (V_{oc}). Finally Si solar cell with 0.5% Cu doped TiO_2 gives high I_{sc}, and V_{oc} values than cells with other concentrations.

Table 3: Comparison of Power Conversion Efficiencies of Different Elements Doped with TiO_2 [13-18].

Element Doped with TiO_2	Molar Concentration (%)	Highest Efficiency (η) (%)
Carbon monoxide (CO)	2	5.66
Cadmium (Cd)	2	3.06
Iron (Fe)	1	2.78
Zinc (Zn)	0.5	6.58
Europium (Eu)	5	2.47
Copper (Cu)	0.5	8.86

Table 3 presents the comparison of power conversion efficiencies of different elements doped with TiO_2. Here 0.5% molar concentration of Cu doped TiO_2 cells gives more efficiency than the other elements of higher concentration doping with TiO_2. Cu effectively increased the short-circuit current (I_{sc}) and power conversion efficiency. It is evident from the present data that Cu doped TiO_2 generates higher power conversion efficiency than other elements.

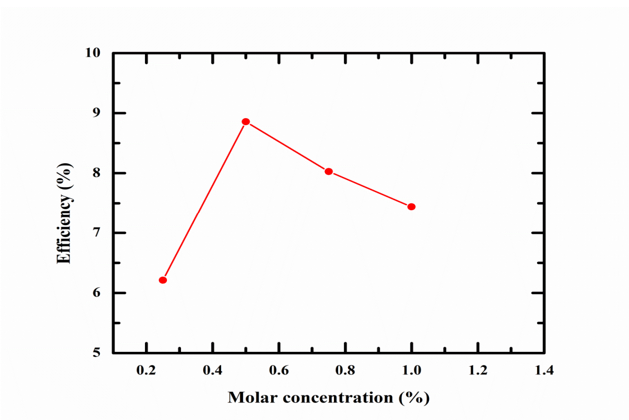

Figure 3: Efficiency Curve of Cu Doped TiO_2 at Different Molar Concentrations

Figure 3 reveals the efficiency of Cu doped TiO_2 at different molar concentrations. Si solar cell obtained high power conversion efficiency at 0.5% molar concentration and gradually decreases as the molar concentration of Cu doped TiO_2 increases.

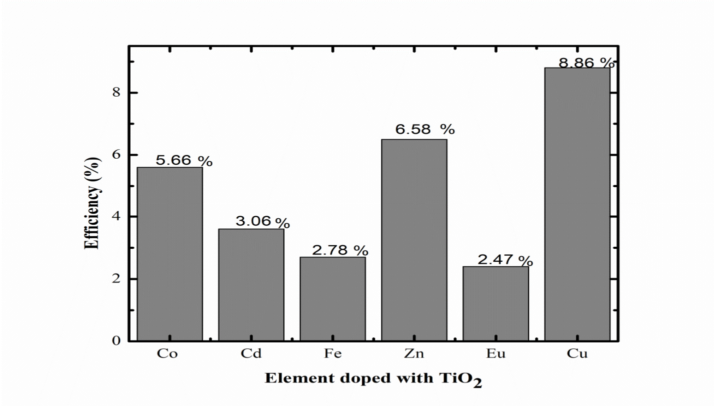

Figure 4: Comparison of Power Conversion Efficiencies of Different Elements Doped with TiO_2 [13-18].

Figure 4 reveals the comparison of power conversion efficiencies of different elements doped with TiO_2. The power conversion efficiencies of doping elements viz., Co, Cd, Fe, Zn, and Eu are low when compared with Cu.

CONCLUSIONS

Quantitative and valuable optimization for fabrication of Si solar cells with Cu doped TiO_2 thin films is taken up in this work. TiO_2 thin films doped with Cu at different concentrations were successfully produced on Si solar cells and tested. Effect of Cu doping on Si solar cells, short circuit current (I_{sc}) generated and power conversion efficiency were estimated. The power conversion efficiency of Cu doped TiO_2 is found increasing with increase in the concentration of copper, reached a maximum and starts decreasing. The optimal concentration where the efficiency is maximum was found to be at 0.5% concentration. Further on comparison with data available in the literature for other doped materials like Fe, Eu, Zn, CO etc., it is inferred that Cu doped TiO_2 has a max conversion efficiency of 8.86%.

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